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Carole R. Engle
Virginia Tech University,, cengle8523@gmail.com

Stephen Clements
Mississippi State University, stephen.a.clements@usda.gov

Brian S. Dorr
brian.s.dorr@aphis.usda.gov

J. Brian Davis
Mississippi State University, brian.davis@msstate.edu

Luke A. Roy
Auburn University, royluke@auburn.edu

See next page for additional authors

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Authors
Carole R. Engle, Stephen Clements, Brian S. Dorr, J. Brian Davis, Luke A. Roy, and Anita M. Kelly

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Economic effects of predation by scaup on baitfish and sportfish farms

Carole R. Engle[1] | Stephen Clements[2] | Brian S. Dorr[3] | J. Brian Davis[2] | Luke A. Roy[4] | Anita M. Kelly[4]

[1]Engle-Stone Aquatic$ LLC, VA Seafood AREC, Virginia Tech University, Hampton, Virginia

[2]Department of Wildlife, Fisheries, and Aquaculture, Mississippi State University, Mississippi State, Mississippi

[3]U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, Mississippi State, Mississippi

[4]School of Fisheries, Aquaculture, & Aquatic Sciences, Alabama Fish Farming Center, Auburn University, Greensboro, Alabama

Correspondence
Carole R. Engle, Engle-Stone Aquatic$ LLC, VA Seafood AREC, Virginia Tech University, Hampton, VA.
Email: cengle8523@gmail.com

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Abstract

Fish-eating birds have been found to consume baitfish and sportfish raised on farms in the United States. Understanding the on-farm economic effects of such wildlife conflicts is essential for wildlife management agencies to make informed decisions. Lesser scaup, while not widely considered a fish-eating bird, will consume farmed fish. Baitfish and sportfish farms in Arkansas (the major baitfish and sportfish producing-state in the U.S.) were surveyed to gather data on the cost of protecting farm crops from scaup. The values of lost sales revenue from the various species of baitfish and sportfish consumed by scaup were estimated based on a concomitant field study on the abundance, distribution, and dietary habits of scaup that visited Arkansas baitfish and sportfish farms during winters of 2016–2017 and 2017–2018. Economic effects were estimated for golden shiner, fathead minnow, sportfish, and goldfish farms. Total annual costs to scare birds from baitfish and sportfish farms were $622 ± 742 per ha. The greatest components of bird-scaring costs were man-power (56%), truck usage (32%), levee upkeep for vehicle access to scare birds (9%), firearms and ammunition (2%), and pyrotechnic devices (1%). The combined annual economic losses, calculated as reduced revenue from fish losses to scaup plus expenditures to scare birds, averaged $683/ha for golden shiners, $695/ha for fathead minnows, $663/ha for sportfish, and $673/ha for goldfish across the two study years. The fish losses to scaup alone averaged $1.06 million per year ($0.09 million in Year 1 and $2.03 million in Year 2) for the Arkansas baitfish industry. Total direct negative economic effects on the Arkansas baitfish industry were estimated to be, on average, $5.5 million per year ($4.6 in Year 1 and $6.3 million in Year 2).

KEYWORDS

aquaculture economics, baitfish, costs to scare birds, fish losses to birds, Lesser scaup, predation

1 | INTRODUCTION

Sportfish and baitfish constitute important segments of U.S. aquaculture, with sportfish the fourth- and baitfish the fifth-greatest (by sales) category of U.S. farm-raised finfish in 2018 (USDA-NASS, 2019). Arkansas produced 68% of all farmed baitfish and 35% of all farmed sportfish (other than trout sold for recreation) sold in the U.S. in 2018.

Baitfish and sportfish have been farmed in the U.S. since the 1940s (University of Arkansas Cooperative Extension Service Program, 1991). Production occurs primarily in traditional earthen ponds on farms that range in size from very small (~5 ha) to more than 500 ha each. The most common baitfish species farmed are golden shiners (*Notemigonus crysoleucas*), fathead minnows (*Pimephales promelas*), and goldfish (*Carassius auratus*), whereas the most commonly raised sportfish are largemouth bass (*Micropterus salmoides*), crappie (*Pomoxis* spp.), and various sunfish (*Lepomis* spp.).

Most baitfish and sportfish farms in Arkansas are located within the Mississippi River Flyway, a historic corridor for millions of migrating waterfowl and other waterbirds (Bellrose, 1980). Use of fish farms by fish-eating birds has been reported to cause substantial losses of farmed fish (Dorr, Burger, Barras, & Godwin, 2012; Dorr, Hanson-Dorr, DeVault, Barras, & Guillaumet, 2014; Dorr, Hatch, & Weseloh, 2014; Glahn & Brugger, 1995; Glahn, Werner, Hanson, & Engle, 2002; Kumar, Hegde, Wise, Mischke, & Dorr, 2020; Stickley Jr., Warrick, & Glahn, 1992; Wywialowski, 1999). While there is a fairly robust literature on predation by fish-eating birds such as the double-crested cormorant, *Phalacrocorax auritus*, on catfish farms (See Burr, Avery, Street, & Strickland, 2020; Burr, Avery, Street, Strickland, & Dorr, 2020; and Christie, 2019 for recent summaries), bird and fish dynamics on baitfish and sportfish farms have not been studied since 2005 (Glahn, Rasmussen, Thomsa, & Preusser, 2011). Previous work focused primarily on effects of predation by wading birds (Hoy, 1994; Hoy, Jones, & Bivings, 1989; Werner, Harrel, & Wooten, 2005). Despite being rather dismissed as a non-fish-eating bird, lesser scaup (*Aythya affinis*) have been observed foraging for fish on baitfish and sportfish ponds (Hoy et al., 1989; Philipp & Hoy, 1997; Werner et al., 2005). Wooten and Werner (2004) found that stomach contents of 26% of the lesser scaup collected contained bones or otoliths of fish, and 11% of scaup contained fish biomass (muscle or skin). Philipp and Hoy (1997) observed as many as 1,000 scaup on a single baitfish pond, and baitfish and sportfish farmers have reported increased concerns over the losses of fish to lesser scaup.

Baitfish and sportfish production and marketing practices are quite different compared to foodfish farms. The fish sold generally are small, and the market demands specific size ranges of baitfish that depend upon the fish species targeted by their angler customers (Stone, Kelly, & Roy, 2016; Stone, Roy, & Park, 2019). Once baitfish and sportfish reach market size, farmers are then challenged to maintain them in the specific size ranges demanded by customers. During winter, baitfish may be stocked at high densities to maintain fish in the appropriate market size ranges. If stocking densities are reduced through predation by fish-eating birds, the remaining baitfish may grow too large for intended markets. Thus, the large, visible ponds in the baitfish and sportfish industry, that are stocked densely with small fish, may encourage feeding opportunities for birds such as lesser scaup and the less common greater scaup (*Aythya marila*); hereafter, scaup.

Werner et al. (2005) estimated expenditures on bird management of $247/ha by baitfish farmers in Arkansas. Expenditures included the purchase of pyrotechnics, propane cannons, air horns, shotguns, and employees (1–10 per farm) to patrol and scare birds. More recently, Engle et al. (2020) found that U.S. catfish farmers incurred costs of $704/ha ± $394/ha in attempts to manage fish-eating birds on their farms. Compared to other costs of raising catfish, expenditures related to bird-scaring were the fifth-greatest cost on catfish farms.

The value of fish losses that occur despite time and money spent on management reduces yields of fish that result in reduced farm sales revenue. Wooten and Werner (2004) estimated values of baitfish consumed by scaup that ranged from $18/ha to $150/ha on a 200-ha farm, depending primarily on the degree of bird foraging pressure in a given year. Moreover, there may be additional economic effects of reduced yields from bird predation from the proportionately greater fixed costs on baitfish compared to other types of aquaculture farms (Engle, 1993; Engle, Kumar, & van Senten, 2020; Engle, Stone, & Park, 2000). Reduced yields result in fewer kilograms of fish across which to spread fixed costs of production and increase costs per kilogram of fish produced (measured as breakeven prices of fish).

The on-going and possibly increasing conflicts between lesser scaup and baitfish farms indicate a strong need to generate contemporary estimates of the effects of predation on baitfish and sportfish farms using improved methods and more rigorous economic analysis. Such studies are needed as farming and other land-use and bird predation patterns change over time. The goal of this study was to assess the economic effects of predation by scaup on baitfish and sportfish ponds. Specifically, the objectives were: (a) to measure on-farm costs of bird management on baitfish and sportfish farms; (b) evaluate effects on sales revenue of fish consumed by scaup; (c) estimate the whole-farm combined economic effects of increased costs to scare birds and reduced revenue from fish losses; and (d) estimate the industry-wide economic impact on the Arkansas baitfish industry.

2 | METHODS

The first step to evaluate the economic effects of fish predation by scaup on baitfish and sportfish ponds was to measure on-farm costs of scaring birds. This economic analysis was a component of a larger study in which wildlife management researchers estimated the abundance of scaup and collected foraging scaup to estimate consumption of baitfish and sportfish on Arkansas fish farms during two winters (2016–2017 and 2017–2018). Details of field collections and data on scaup abundance and dietary habits can be found in Clements (2019) and Clements et al. (2020).

A survey was conducted in 2017 of the baitfish and sportfish farms participating in the study to obtain farm-level data on bird-scaring costs. A questionnaire was developed and e-mailed to baitfish farmer study participants. Follow-up reminders and telephone calls were made as necessary. Data were collected on purchases of firearms, ammunition, pyrotechnics, optics, eye and ear protection, exclusion devices, levee repairs, gravel, and expenses of trucks and drivers for the previous bird-scaring season (winter 2016–2017). Respondents were further asked if those costs were typical of other years; if not, to report what more typical bird-scaring costs were. The overall response rate was 93%. Follow-up checks were made in 2018 as to whether bird-scaring costs for the winter of 2017–2018 had changed substantially from those reported in 2017.

Questionnaire responses were coded and entered into a spreadsheet for subsequent analysis. Each response was converted into standard units of measure that allowed summing within cost categories that included expenditures on firearms and ammunition (including costs of shipping), pyrotechnics, optics, eye and ear protection, and exclusion devices. Respondents also provided information on the number of employees that were tasked with scaring birds, the amount of time spent doing so (hours per day, days per week, weeks per year), and wages paid. Respondents also reported on vehicle usage (primarily trucks) to scare birds. The numbers and types of vehicles, mileage expended, and fuel, repair, and maintenance costs for the months in which those vehicles were used to scare birds were also recorded. Costs to repair and maintain levees for access of trucks to be able to scare birds included purchases and delivery of gravel to keep levees passable.

Expenses for scaring birds were summed by farm observation. To obtain bird-scaring expenses per ha, the total bird-scaring cost per farm was divided by the total ha of water in production that year. Scatterplots were examined to evaluate whether there was a relationship between per-ha bird-scaring costs and farm size.

The second step in the analysis of the economic effects of predation by scaup on baitfish and sportfish farms was to estimate the value of the fish lost directly to predation. Clements (2019) estimated the abundance of scaup and collected foraging scaup to estimate consumption of baitfish and sportfish on Arkansas fish farms during two winters: 2016–2017 (Year 1) and 2017–2018 (Year 2). Values adapted from Clements (2019) of scaup use per pond per day were multiplied by the number of ponds, the number of days per month, the percent of days that scaup consumed fish in that given month, and the weight (kg) of fish consumed per scaup during that month. Clements (2019) only reported sunfish (*Lepomis* spp.) consumption by scaup from sportfish ponds. Monthly losses were summed for each farm observation and divided by the water surface area (ha) in production that year which yielded an estimate of total losses (in kg/ha) for that year of the study.

The third step was to evaluate the whole-farm combined economic effects of fish losses and bird-scaring expenses. Whole-farm enterprise budgets were used as the basis for this analysis because of the proportionately greater on-farm economic effects of variations in yield on breakeven prices on baitfish and sportfish farms compared to other types of aquaculture farms (Engle, 1993; Engle et al., 2000; Engle, Kumar, & van Senten, 2020; Pounds, Engle, & Dorman, 1992; van Senten, Dey, & Engle, 2018). Thus, comprehensive whole-farm enterprise budget models representative of the Arkansas baitfish industry were developed for golden shiners, fathead minnows, sportfish, and goldfish based on commercial farm survey data (Horne Stone, & Engle, 2010; van Senten & Engle, 2017); valuation methods and procedures were from Engle (2010). Details on the comprehensive budgets developed for this analysis are available in Engle et al. (2020). A farm size of 121 ha was used for all four species to standardize fixed costs across analyses. Because golden shiner and fathead minnow farms exhibit a broader range of farm sizes than goldfish or sportfish farms, additional enterprise budgets were developed for 486-ha golden shiner and fathead minnow farms.

The whole-farm economic models reflected the current cost and revenue structure for each segment (golden shiners, fathead minnows, sportfish, and goldfish) of baitfish and sportfish farms and were designated as the "current status" scenario. Current status budgets included farm expenditures to scare birds and the reduced harvest levels of fish resulting from bird predation. Net returns, breakeven prices above variable and total costs, and breakeven yields above variable and total costs were recorded for each of the six enterprise budgets developed. These included 121-ha and 486-ha farms for golden shiners and fathead minnows and 121-ha farms for sportfish and goldfish) for the current status scenario. Each budget was then run with yields adjusted to remove the effects of fish losses for each species/farm size and then repeated with bird-scaring expenses removed. Because of the variability between study years in the numbers of birds feeding on baitfish and sportfish farms (Clements, 2019), each budget and scenario were run with data for each year of the study. To provide some measure of the risk faced by baitfish and sportfish farms, each model was further run with the greatest observed losses on an individual farm and repeated for the least amount of losses observed per individual farm.

Analysis of results from the economic models for the various species/farm size scenarios focused first on whole-farm cost effects. Breakeven prices above variable costs were used to measure the costs of production in $/kg of fish sold with respect to only the variable operating costs, while breakeven prices above total costs accounted for all production costs, including non-cash costs of annual depreciation.

Effects on farm revenue and profitability from the economic models were measured by income above variable cost and by net returns. Both metrics were calculated per ha. Income above variable cost reflected shorter-term effects on profitability, whereas net returns reflected long-term profitability and included the effects of fixed resources of management, land, existing ponds, and other infrastructure.

Finally, an analysis of the estimated economic effects across the entire Arkansas baitfish industry was conducted. The Census of Aquaculture (USDA-NASS, 2019) data were used to estimate the kilograms produced of the three baitfish species (golden shiners, fathead minnows, and feeder goldfish) raised in Arkansas in 2018 by dividing total Arkansas sales by the average price for each species. The effect of the fish losses and bird-scaring costs per kilogram were then multiplied by the total quantity of kilograms for each species and the values were summed. The census data did not provide sufficient resolution to include sportfish in this calculation, nor did it provide area in production by state for each sportfish species that would have allowed for calculation of effects on a per-ha basis.

3 | RESULTS

3.1 | Bird-scaring costs

The overall bird-scaring cost, averaged across all farms, was \$622 ± 742 per hectare of baitfish and sportfish farms. This value represents the fourth to the eighth-greatest cost of producing baitfish and sportfish, depending on the fish species raised (Table 1). Bird-scaring costs were variable across individual farms, ranging from \$59/ha to \$2,361/ha (data not shown). There was no apparent relationship between the size of farm or species raised and the bird-scaring costs per ha (best fit was polynomial; R^2 = 0.04). The highest-cost observations were three to seven times greater than the mean cost of the remaining observations; the high-cost observations included the smallest, largest, and some medium-sized farms. Data were verified with follow-up contacts to confirm that these observations were valid data, not outliers. Results suggest that factors other than farm size drive the per-ha bird-scaring costs.

Manpower composed 56% of the cost of scaring birds, followed by 32% for the costs of truck usage, 9% for levee upkeep (to allow truck access to scare birds), 2% for firearms and ammunition, and only 1% of costs were for scaring devices (Figure 1). On average, one truck and one driver were used per 154 ± 144 ha of water surface area. Time spent by employees to scare birds averaged 3 ± 2 months per person for 19 ± 9 hr/week to scare birds.

3.2 | Effects on costs of production of reduced yield from fish losses and from expenditures to scare birds

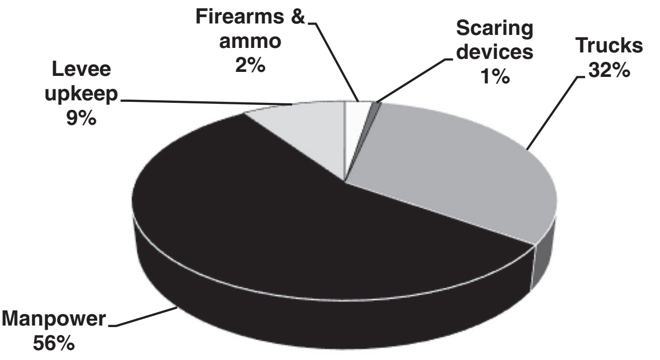
The effects on variable and total costs of production by species group, years, and farm size were examined for three scenarios: (a) current status; (b) removing bird-scaring costs and lost sales revenue from Year 1 fish losses; and (c) removing bird-scaring costs and lost sales revenue from Year 2 fish losses. The breakeven prices (costs of production in \$/kg of fish sold) above variable and total costs thus reflect the corresponding decreased cost of production after removing bird-scaring costs and fish losses from scaup predation from the economic models. There was little difference in breakeven prices above variable costs of the current status scenario with the other two scenarios across species (Figures 2–5).

Greater economic effects were found when examining breakeven prices above total costs between the current status scenario and the other two scenarios (Figures 2–5). For golden shiners, removal of bird-scaring costs and fish losses resulted in decreases in breakeven price above total cost from the current status scenario of \$1.30 and \$1.67/kg (9 and 12%), respectively, at Year 1 and 2 predation levels (Figure 2). Between the two farm sizes of golden shiners, breakeven prices above total costs were lower for the larger, as compared to the smaller, farm. Results for the fathead minnow farm scenarios modeled showed similar trends, although at overall greater breakeven prices, with breakeven prices decreasing by \$3.05/kg and \$4.52/kg (10.8 and 16.1%), respectively, when bird-scaring expenditures and fish losses for Year 1 and

TABLE 1 Costs ($/ha) of scaring birds on commercial baitfish/sportfish farms, compared to other major costs

Species	Interest on long-term investment	Depreciation	Labor	Feed	Amendments (i.e., fertilizer)	Repairs	Scaring birds	
							Costs ($/ha)	Rank in terms of cost/ha
Golden shiners								
121-ha farm	$1,969	$1,183	$918	$640	$165	$269	$622 ± $742	Fifth
486-ha farm	$1,895	$1,090	$1,165	$640	$165	$269	$622 ± $742	Fifth
Fathead minnows								
121-ha farm	$1,969	$1,183	$765	$320	$215	$135	$622 ± $742	Fourth
486-ha farm	$1,895	$1,090	$687	$320	$215	$135	$622 ± $742	Fourth
Goldfish								
121-ha farm	$1,930	$1,173	$918	$991	$948	$815	$622 ± $742	Eighth
Sportfish								
121-ha farm	$1,902	$1,142	$765	$1,149	$124	$343	$622 ± $742	Fifth

FIGURE 1 Percentage of line-item expenditures that contributed to costs of scaring avian predators from baitfish/ sportfish farms



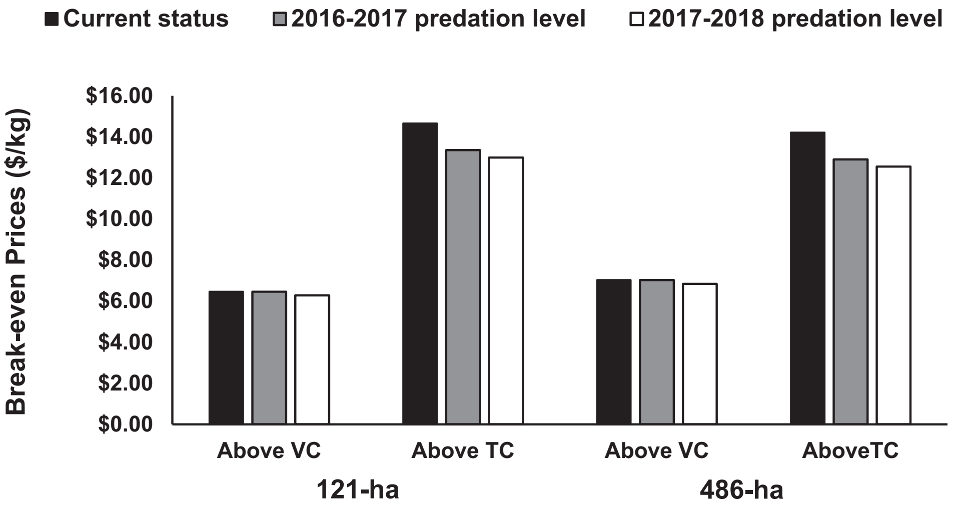


FIGURE 2 Break-even prices above variable (VC) and total (TC) costs of the current status scenario and 2016–2017 and 2017–2018 predation levels (removing lost sales revenue from fish losses and bird-scaring costs), 121- and 486-ha golden shiner farms

2 predation levels were removed (Figure 3). For sportfish production after removing bird-scaring expenditures and fish losses, production costs decreased by $1.30/kg (8.2%) and $1.53/kg (9.6%), respectively, for Year 1 and 2 predation levels, respectively (Figure 4). For goldfish, removing bird-scaring costs and fish losses reduced production costs by $0.59/kg and $0.62/kg (6.0 and 6.3%) at Year 1 and 2 predation levels, respectively (Figure 5).

Figures 6–8 show the relative decreases in breakeven prices on farms/years after removing bird-scaring costs and lost sales revenue of the greatest and the least fish losses because of scaup predation. Breakeven prices above total costs decreased from those of the current status scenario by 14% for golden shiners, 27–28% for fathead minnows, and 17% for sportfish[1] with removal of bird-scaring costs and the greatest fish losses observed.

3.3 | Effects on revenue from fish losses

In addition to effects on costs, scaup predation on baitfish and sportfish farms reduces revenue through lower yields of fish harvested because of the fish consumed by scaup. Table 2 presents the percentage reduction in average yields of baitfish and sportfish from scaup predation under the least and greatest fish losses measured. At least one farm in each species group had no observed fish losses during at least one of the study years. Thus, the least effect

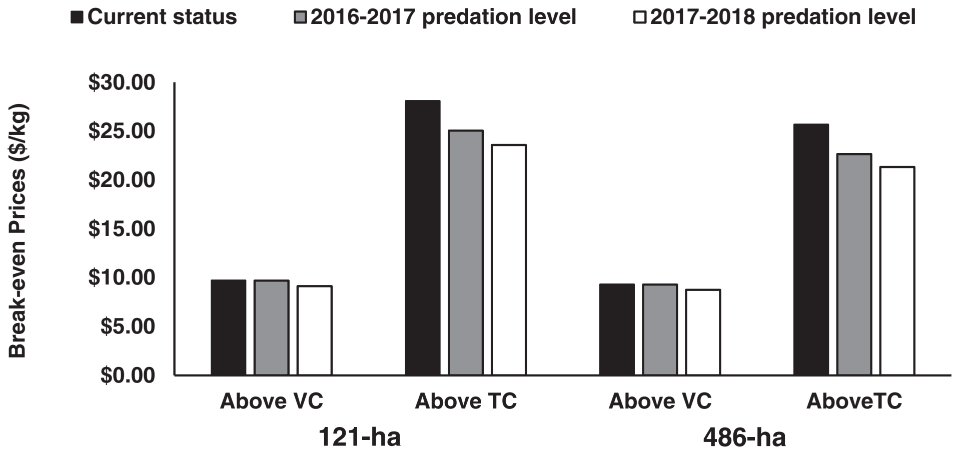


FIGURE 3 Breakeven prices above variable (VC) and total (TC) costs of the current status scenario and 2016–2017 and 2017–2018 predation levels (removing lost sales revenue from fish losses and bird-scaring costs), 121- and 486-ha fathead minnow farms

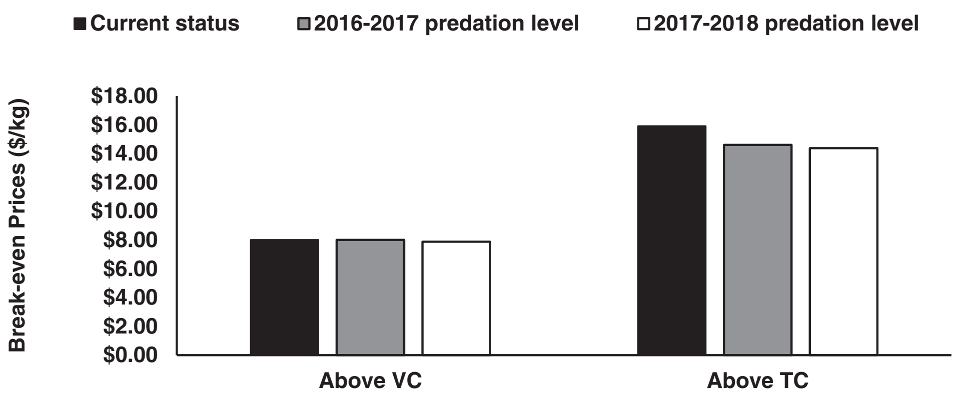


FIGURE 4 Breakeven prices above variable (VC) and total (TC) costs of the current status scenario and 2016–2017 and 2017–2018 predation levels (removing lost sales revenue from fish losses and bird-scaring costs), 121-ha sportfish farms

observed was no reduction in yield. The next lowest percentage yield losses were those observed in Year 1. Losses were greater in Year 2, when more birds arrived to feed on baitfish and sportfish farms than in Year 1. Some farms experienced greater bird pressure in some years than did others. The greatest fish losses observed on any given farm offer an example of the greatest potential losses on farms. The greatest potential fish losses observed in this study included 5.9% of farm-wide yield of golden shiners, 22.9% of fathead minnows, and 10.8% of sportfish.[1]

3.4 | Effects on profitability

Table 3 shows the change in profitability (income above variable costs and net returns) on golden shiner farms because of the reduced revenue of fish losses alone and also of the value of fish losses combined with bird-scaring costs. In Year 1, the reduced revenue effects from fish losses alone were negligible. In Year 2, however, with greater scaup foraging pressure, the fish losses alone resulted in reduced profitability of $122/ha. When also accounting for bird-scaring costs, profitability

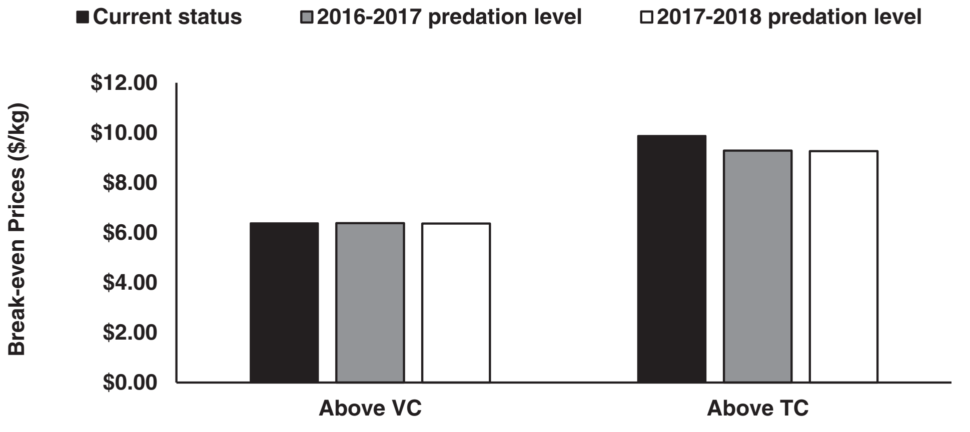


FIGURE 5 Breakeven prices above variable (VC) and total (TC) costs of the current status scenario and 2016–2017 and 2017–2018 predation levels (removing lost sales revenue from fish losses and bird-scaring costs), 121-ha goldfish farms

FIGURE 6 Breakeven prices above variable (VC) and total (TC) costs for the current status scenario and for economic effects of removing the greatest and least fish losses (and bird-scaring costs), 121- and 486-ha golden shiner farms

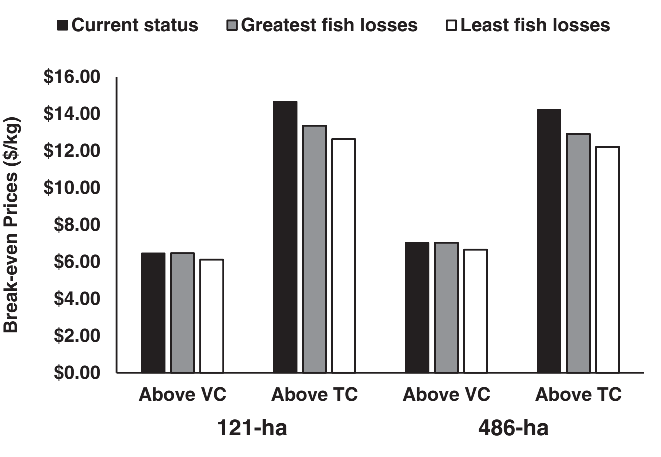
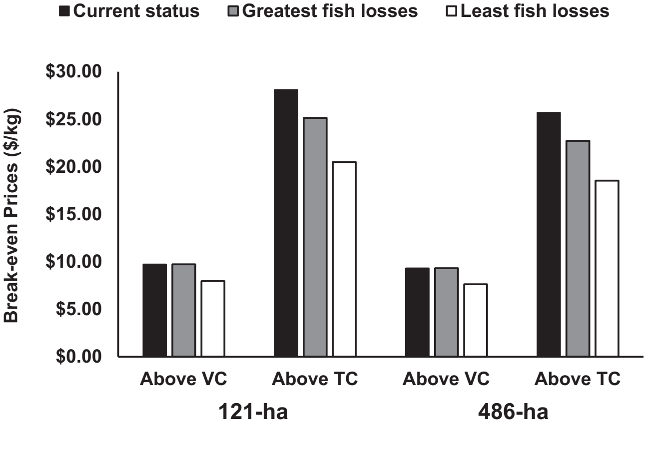


FIGURE 7 Breakeven prices above variable (VC) and total (TC) costs for the current status scenario and for economic effects of removing the greatest and least fish losses (and bird-scaring costs), 121- and 486-ha fathead minnow farms



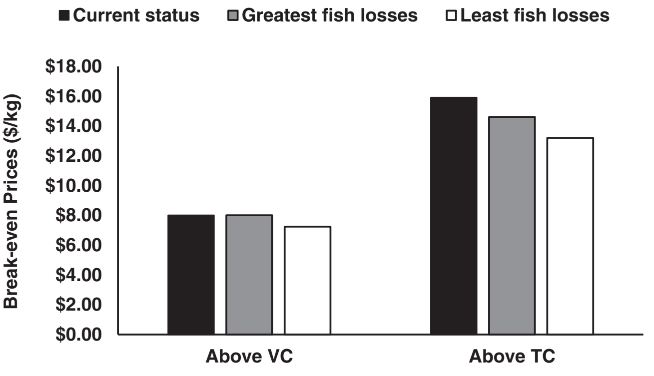


FIGURE 8 Breakeven prices above variable (VC) and total (TC) costs for the current status scenario and for economic effects of removing the greatest and least fish losses (and bird-scaring costs), 121-ha sportfish farms

TABLE 2 Fish losses to scaup on baitfish/sportfish farms as a percentage of total yields

Scenario	Golden shiners	Fathead minnows	Sportfish[a]	Goldfish
2016–2017	0.04%	0.35%	0.001%	0.00%
2017–2018	2.9%	6.7%	1.6%	0.27%
Lowest fish losses	0%	0%	0%	n.a.[b]
Greatest fish losses	5.9%	22.9%	10.8%	n.a.[b]

[a]Primarily sunfish (*Lepomis* spp.).

[b]There were too few observations of goldfish farms to report.

decreased by $743/ha. For the farm with the greatest losses of fish from scaup depredation, the reduced income above variable costs was $247/ha for fish losses alone and $868/ha when bird-scaring costs were included.

Revenue losses and reduced profitability effects were greater on fathead minnow farms than on golden shiner farms (Table 4). In Year 1, the effects on profitability were minimal when considering only the value of fish losses. In Year 2, however, with greater scaup foraging pressure, the profitability was reduced by $139/ha from fish losses alone, and increased to $760/ha when bird-scaring costs were included. For a farm that experienced very heavy predation by scaup in any given year, losses could be as high as $478/ha from fish losses alone and $1,100/ha when bird-scaring costs were included.

Average predation levels, as a percentage of total yields, were lower on sportfish farms than on golden shiner and fathead minnow farms and resulted in proportionately lower negative effects on revenue and profitability when considering only fish losses (Table 5). When accounting for bird-scaring costs, however, profitability was reduced by $622/ha in Year 1 and $705/ha in Year 2. Despite the generally lower effects on profitability on sportfish farms, the greatest overall losses per ha were observed on a sportfish farm; thus, when scaup do target ponds on a sportfish farm, losses to fish alone were found to be as high as $554/ha and $1,176/ha when bird-scaring costs were included.

There are fewer goldfish farms than other types of baitfish and sportfish farms. In addition, scaup use of goldfish ponds was less frequent, often in colder months, and often targeted just a few ponds (Clements, 2019). Nevertheless, when scaup did arrive on goldfish ponds, they fed voraciously, taking advantage of the tendency of goldfish to "ball up" and perhaps be more sluggish because of the colder weather (Clements, 2019). Overall, the fish losses on goldfish farms were negligible in Year 1, but $685/ha in Year 2 when bird-scaring costs were included (Table 6).

3.5 | Industry-wide effects

Across the Arkansas baitfish industry, average annual fish losses because of scaup predation were $292,081 for golden shiner farms, $766,473 for fathead minnow farms, and $1,454 for goldfish farms, totaling $1.06 million annually across

TABLE 3 Reductions in profitability because of scaup predation on golden shiner farms. Values represent the reduced revenue/profits for either the fish losses alone or fish losses combined with bird-scaring costs

	121-ha farm		486-ha farm	
	Fish losses alone	Fish losses + bird-scaring costs	Fish losses alone	Fish losses + bird-scaring costs
2016–2017				
Income above variable costs ($/farm)	−185	−185	−739	−739
Income above variable costs ($/ha)	−2	−2	−2	−2
Net returns ($/farm)	−185	−75,692	−739	−302,767
Net returns ($/ha)	−2	−623	−2	−623
2017–2018				
Income above variable costs ($/farm)	−14,766	−14,766	−59,064	−59,064
Income above variable costs ($/ha)	−122	- 122	−122	−122
Net returns ($/farm)	−14,766	−90,273	−59,064	−361,092
Net returns ($/ha)	−122	−743	−122	−743
Average 2016–2017 and 2017–2018				
Income above variable costs ($/farm)	−7,475	−7,475	−29,902	−29,902
Income above variable costs ($/ha)	−62	−62	−62	−62
Net returns ($/farm)	−7,475	−82,982	−29,902	−331,930
Net returns ($/ha)	−62	−683	−62	−683
Least fish losses				
Income above variable costs ($/farm)	—	—	—	—
Income above variable costs ($/ha)	—	—	—	—
Net returns ($/farm)	—	−75,507	—	−302,028
Net returns ($/ha)	—	−622	—	−622
Highest fish losses				
Income above variable costs ($/farm)	−29,959	−29,959	−119,838	−119,838
Income above variable costs ($/ha)	−247	−247	−247	−247
Net returns ($/farm)	−29,959	−105,466	−119,838	−421,866
Net returns ($/ha)	−247	−868	−247	−868

the Arkansas baitfish industry (Table 7). Sportfish were excluded from this analysis because of insufficient resolution of census data to allow for these calculations. Arkansas losses across the three baitfish species were $88,181 in Year 1 and $2.03 million in Year 2. Finally, when combined with bird-scaring costs, total direct negative economic effects across the Arkansas baitfish industry averaged $5.5 million, with $4.6 million in Year 1 and $6.3 million in Year 2.

4 | DISCUSSION

Avian predation of fish crops has led baitfish and sportfish farmers to spend time and money in attempts to manage birds and prevent losses of fish. Birds such as scaup, however, continue to consume fish on baitfish and sportfish farms despite efforts by farmers to prevent such losses. This study measured on-farm costs to scare birds from these fish farms, evaluated the effects on farm revenue of fish losses to scaup; estimated the whole-farm economic effects of increased costs to scare birds and the reduced revenue from fish losses; and estimated industry-wide economic

TABLE 4 Reductions in profitability because of scaup predation on fathead minnow farms

	121-ha farm		486-ha farm	
	Fish losses alone	Fish losses + bird-scaring costs	Fish losses alone	Fish losses + bird-scaring costs
2016–2017				
Income above variable costs ($/farm)	−883	−883	−3,532	−3,532
Income above variable costs ($/ha)	−8	−7	−7	−7
Net returns ($/farm)	−883	−76,390	−3,532	−305,560
Net returns ($/ha)	−7	−629	−7	−629
2017–2018				
Income above variable costs ($/farm)	−16,861	−16,861	−67,443	−67,443
Income above variable costs ($/ha)	−139	−139	−139	−139
Net returns ($/farm)	−16,861	−92,368	−67,443	−369,471
Net returns ($/ha)	−139	−760	−139	−760
Average 2016–2017 and 2017–2018				
Income above variable costs ($/farm)	−8,872	−8,872	−35,487	−35,487
Income above variable costs ($/ha)	−73	−73	−73	−73
Net returns ($/farm)	−8,872	−84,379	−35,487	−337,515
Net returns ($/ha)	−73	−695	−73	−695
Least fish losses				
Income above variable costs ($/farm)	—	—	—	—
Income above variable costs ($/ha)	—	—	—	—
Net returns ($/farm)	—	−75,507	—	−302,028
Net returns ($/ha)	—	−622	—	−622
Highest fish losses				
Income above variable costs ($/farm)	−58,060	−58,060	−232,241	−232,241
Income above variable costs ($/ha)	−478	−478	−478	−478
Net returns ($/farm)	−58,060	−133,567	−232,241	−534,269
Net returns ($/ha)	−478	−1,100	−478	−1,100

Note: Values represent the reduced revenue/profits for either the fish losses alone or fish losses combined with bird-scaring costs.

effects. While this study focused only on losses from scaup, other birds have been shown to forage on baitfish and sportfish crops (Hoy et al., 1989; Philipp & Hoy, 1997; Werner et al., 2005). Thus, the economic values of fish losses estimated in this study do not reflect the total fish losses to avian predators on baitfish and sportfish farms. The bird-scaring costs, however, do reflect total bird management efforts on farms. Management efforts targeted all birds that arrived on ponds to forage from the time that birds were first sighted on ponds and without respect to which specific species were there on a given day. Thus, it is not possible to apportion the bird-scaring efforts to effects of a single species. Additional work is needed to examine the total on-farm economic effects of fish losses from all bird species foraging on farmed baitfish and sportfish.

The only previous estimates of bird-scaring costs on baitfish and sportfish farms were those of Werner et al. (2005). When adjusted to 2018 dollars,[2] bird-scaring costs from Werner et al. (2005) were reported to be $469/ha. By comparison, results from this study demonstrated an overall average bird-scaring cost that was approximately one-third greater (at $622 ± 742 per hectare) than the inflation-adjusted values reported by Werner

TABLE 5 Reductions in profitability because of scaup predation on sportfish[a] farms

	Fish losses alone	Fish losses + bird-scaring costs
2016–2017		
Income above variable costs ($/farm)	−7	−7
Income above variable costs ($/ha)	−0	−0
Net returns ($/farm)	−7	−75,514
Net returns ($/ha)	−0	−622
2017–2018		
Income above variable costs ($/farm)	−10,133	−10,133
Income above variable costs ($/ha)	−83	−83
Net returns ($/farm)	−10,133	−85,640
Net returns ($/ha)	−83	−705
Average 2016–2017 and 2017–2018		
Income above variable costs ($/farm)	−5,070	−5,070
Income above variable costs ($/ha)	−42	−42
Net returns ($/farm)	−5,070	−80,577
Net returns ($/ha)	−42	−663
Least fish losses		
Income above variable costs ($/farm)	—	—
Income above variable costs ($/ha)	—	—
Net returns ($/farm)	—	−75,507
Net returns ($/ha)	—	−622
Highest fish losses		
Income above variable costs ($/farm)	−67,285	−67,285
Income above variable costs ($/ha)	−554	−554
Net returns ($/farm)	−67,285	−142,792
Net returns ($/ha)	−554	−1,176

Note: Values represent the reduced revenue/profits for either the fish losses alone or fish losses combined with bird-scaring costs.
[a]Primarily sunfish (*Lepomis* spp.).

et al. (2005). Results from the current study were more similar to the $704 ± 394/ha reported to be expended by catfish farmers during the same study years (Engle, Christie, et al., 2020). Bird-scaring costs in this study were similar between the two years of the study, averaging $638 ± 609 per ha in Year 1 and $655 ± $634/ha in Year 2, despite the different levels of scaup foraging pressure in the two years. Werner et al. (2005) did not report per-farm costs to scare birds; thus, comparison of between-farm variability with the previous study is not possible. There was substantial variability in bird-scaring costs among farms in each study year in the current study (coefficient of variation = 95% in Year 1, 97% in Year 2, and 119% when all observations were averaged across both years). Bird-scaring costs per ha did not appear to be associated with the fish losses estimated for individual farms. The between-farm variation in bird-scaring costs may reflect preferences by birds for specific farms because of location or management practices. The large variability in bird-scaring costs suggest opportunity for increasing efficiency of bird depredation management efforts. For example, Clements et al. (in review) suggested that scaup were found more often on larger baitfish and sportfish ponds with higher stocking densities that were located at a greater distance from major rivers.

TABLE 6 Reductions in profitability because of scaup predation on goldfish farms

	Fish losses alone	Fish losses + bird-scaring costs
2016–2017		
Income above variable costs ($/farm)	−4	−4
Income above variable costs ($/ha)	−0	−0
Net returns ($/farm)	−4	−80,311
Net returns ($/ha)	−0	−661
2017–2018		
Income above variable costs ($/farm)	−2,866	−2,866
Income above variable costs ($/ha)	−24	−24
Net returns ($/farm)	−2,866	−83,161
Net returns ($/ha)	−24	−685
Average 2016–2017 and 2017–2018		
Income above variable costs ($/farm)	−1,435	−1,435
Income above variable costs ($/ha)	−12	−12
Net returns ($/farm)	−1,435	−81,736
Net returns ($/ha)	−12	−673

Note: Values represent the reduced revenue/profits for either the fish losses alone or fish losses combined with bird-scaring costs.

TABLE 7 Industry-wide total direct economic effects of bird predation. on Arkansas baitfish farms[a]

Species	Value of fish losses	Total direct economic effects
Golden shiners		
Average	−$292,081	- $2,146,809
2016–2017	−$7,485	−$1,888,810
2017–2018	−$576,676	−$2,404,808
Fathead minnows		
Average	−$766,473	−$3,623,628
2016–2017	−$80,691	−$2,654,450
2017–2018	−$1,452,254	−$3,872,805
Goldfish		
Average	−$1,454	−$65,078
2016–2017	−$5	−$63,723
2017–2018	−$2,904	−$66,434
Total		
Average	−$1,060,008	−$5,475,515
2016–2017	−$88,181	−$4,606,983
2017–2018	−$2,031,834	−$6,344,047

[a]Insufficient national data were available to estimate industry-wide losses for sportfish.

Baitfish and sportfish consumed by scaup result directly in reduced sales revenue because the fish consumed by scaup, while small, are market-sized product. While scaup are not traditionally considered to be fish-eating birds, Clements (2019) found that 51% of the scaup sampled in Year 2 had eaten fish from baitfish and sportfish ponds.

Individual scaup were found to consume approximately 0.23 kg of fish per day. The greater consumption of baitfish and sportfish in Year 2 of the study was attributed to the much colder temperatures as compared to Year 1. Thus, fish losses to scaup predation appear to be variable and may depend on winter temperatures.

Fish losses observed in this study resulted in reductions in profitability across farms. When considering only the variable operating costs of production (measured as income above variable costs), losses were negligible in Year 1, but ranged from $24 to $139/ha in Year 2, depending on the species. The farms that experienced the greatest fish losses had economic losses above variable costs that ranged from $247/ha to $554/ha. Clearly, scaup have potential to cause serious economic losses on baitfish and sportfish farms, particularly during colder winters. The lowest average effects were on goldfish farms. There were, however, fewer direct observations of predation by scaup on goldfish ponds because there are fewer farms that raise goldfish in the study area. Moreover, bird use of goldfish ponds was quite different from usage of other baitfish farms. Scaup would be absent from goldfish ponds for months, but then would arrive and forage often during the coldest weather, but only on a few particular ponds. The scaup on those ponds visited would gorge themselves on goldfish that may have been sluggish because of the colder weather (Clements, 2019). Goldfish do not swim quickly and may be easier prey for scaup, which are not as agile as some other diving birds (Clements, 2019).

Other types of negative economic effects occur from baitfish and sportfish losses to birds because of the unique types of markets supplied. The end customers for baitfish and sportfish are anglers who target different species for fishing that require different sizes of baitfish. Baitfish and sportfish farmers raise fish to appropriate market sizes before winter and then hold them at a stocking density known to maintain that size until sold the following spring. Predation by birds on baitfish and sportfish ponds reduces the density of the fish stocked and can result in compensatory growth. Such additional growth may make the fish less marketable or potentially un-marketable if they exceed the acceptable market size for their customers.

The lost revenue on baitfish and sportfish farms occurs despite efforts by farmers to manage birds with various types of harassment efforts. This study did not measure the severity of losses in the absence of management efforts; it would have been unreasonable to ask study participants to not scare birds to measure how great the losses would be. For catfish production, Hegde and Kumar (2019) reported that crop losses to predation by double-crested cormorants can result in mortality rates 14–38% greater than typical mortality rates on catfish farms in the absence of management efforts. Hegde and Kumar (2019) based their results on measured losses in commercial-sized research ponds in a year in which the experimental research station had been unable to obtain a permit to scare birds.

Fixed costs tend to be relatively greater on baitfish and sportfish farms (Engle, 1993; Engle et al., 2000; Engle, Kumar, & van Senten, 2020) compared to aquaculture farms with foodfish that are fed at high rates. As a result, changes in yields on baitfish and sportfish farms tend to have a relatively greater effect on overall costs of production. The sensitivity of the economics of baitfish and sportfish farms to yield is enhanced by the relatively low yields overall of baitfish and sportfish (for example, 477 kg/ha for goldens shiners and 239 kg/ha for fathead minnows). Thus, a given weight of fish lost to birds in a lower-yielding segment of aquaculture such as baitfish and sportfish results in a proportionately greater negative effect on breakeven prices above total costs because there are proportionately fewer kilograms of product across which to spread the higher fixed costs.

In this study, breakeven prices for fathead minnows tended to be greater than for golden shiners because their yields were approximately half those of golden shiners. The generally lower yields of fathead minnows, for a given level of predation, then result in proportionately greater percentages of overall yield losses that, in turn, result in greater negative effects on yields and profits.

Baitfish and sportfish farmers tended to implement bird-scaring practices as soon as birds were observed to arrive on the farm in any given year, without knowing whether their farm will be affected strongly or only slightly by bird predation. Thus, bird-scaring costs are incurred regardless of the level of production anticipated, making bird-scaring costs a type of fixed cost. In this study, the total economic losses (which included effects of lost revenue and increased bird-scaring costs) were still $623/ha in Year 1 despite few losses to scaup, while costs were $743/ha in Year 2 with much greater bird pressure.

The degree of risk involved in whether or not birds land on specific farms in any given year is evident in the differences between the economic effects of the greatest and the least fish losses observed. In years with high bird pressure and substantial fish losses, total economic losses were $868/ha for golden shiners, $1,100/ha for fathead minnows, and $1,176/ha for sportfish farms. This potential for substantial negative economic effects prompts farms to initiate comprehensive and costly bird management programs each year without knowing whether the pressure on their farms will be high or low in that year. In this sense, bird management is performed to minimize their risk of losses. Unfortunately, farms still lose fish despite concerted attempts, but are not compensated for the losses or the expenses incurred to manage the birds. Aquaculture farms are not eligible for programs such as the Livestock Indemnity Protection (LIP) that covers cattle losses because of attacks by avian predators. In some sense, baitfish and sportfish farms may be suffering a type of externality in that birds are using fish farms given prior public investments to reduce wetland areas to control malaria, conversion to other anthropogenic uses, and for flood control. Evidence suggests that fish farms provide an ecosystem service in the form of providing habitat for a variety of wildlife, including birds (Seafood Watch, 2017). Feaga, Vilella, Kaminski, and Davis (2015) found that dozens of birds from different guilds use aquaculture farms in the Mississippi Delta. In fact, some bird-watching guides explicitly identify fish farms as best locations for bird watching (White, 1995).

5 | CONCLUSIONS

This study provided detailed and comprehensive measures of the time and expense by baitfish and sportfish farmers to manage birds that arrive at their farms to forage on fish crops. Results show that the farm-level expenditures (adjusted to 2018 dollars) to manage birds appear to have increased over time. Baitfish and sportfish farmers were found to spend $622 ± 742/ha to scare birds, making bird-scaring costs the fourth to the eighth greatest cost of production, depending on the species raised. The greatest cost components to manage birds were manpower (56%), truck usage (32%), levee upkeep (9%), with much lower costs for firearms, ammunition, and pyrotechnics devices.

Total economic losses (effects of reduced revenue and bird-scaring costs) ranged from $623/ha to $743/ha on golden shiner farms, $629 to $760/ha on fathead minnow farms, $622 to $705/ha on sportfish farms, and $661/ha to $685/ha for goldfish farms for years of slight bird pressure (Year 1) and years of greater bird pressure (Year 2), respectively. Across the Arkansas baitfish industry, total direct negative economic effects averaged $5.5 million. The economic losses found in this study provide a basis for assessing state and federal policy options related to on-going wildlife conflicts on aquaculture farms.

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ORCID

Carole R. Engle https://orcid.org/0000-0001-7055-0479
Stephen Clements https://orcid.org/0000-0001-9511-5481
Luke A. Roy https://orcid.org/0000-0003-4498-6871
Anita M. Kelly https://orcid.org/0000-0002-9657-6594

ENDNOTES

[1] There were too few samples of bird predators on goldfish farms to make this same comparison.

[2] Using Producer's Price Index, from Bureau of Labor Statistics. Available at: www.bls.gov/ppi.

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